The Use of a Capillary as a Sensor of Cavitation

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Abstract. The dramatic rise in height of the meniscus within a capillary, the other end of which is immersed in a liquid undergoing ultrasonic cavitation, represents a novel, robust and inexpensive method for monitoring cavitational activity. Here this effect is compared quantitatively with the multibubble sonoluminescence, which is simultaneously being emitted by the sample. A comparison is made of both the thresholds of the two measures, and of their magnitudes in the super-threshold condition

INTRODUCTION

The normal rise of a liquid in a capillary, the lower end of which is placed in a liquid bath, is dramatically increased by order of metres when ultrasonic cavitation is induced in that bath [1, 2]. The magnitude of the effect can be monitored either by this height rise, or by the additional pressure required to keep the meniscus stationary (the method used in this paper). In comparing the possible explanations for this effect, Dezhkunov and Prokhorenko [1-3] argued that, of the various acoustic and hydrodynamic phenomena, which can contribute to such a response, the contribution from cavitational activity (specifically, jetting) greatly outweighs that from other sources. This would suggest that the effect might make a suitable monitor for cavitation. These propositions are tested in this paper, first by comparing the threshold conditions required to induce the ultrasonic capillary effect (UCE) and to generate sonoluminescence (SL); and second, by examining the magnitude of the two effects in super-threshold conditions.

METHOD

The apparatus is shown in Fig.1. The test chamber represents a glass cylinder with a diameter of 80 mm and height of 210 mm (internal dimensions). It was equipped with a coiled glass tube through which a temperature-controlled liquid was pumped. Glass capillaries with inner diameter 0.15 mm and wall thickness 1.8 mm

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were used in experiments. The source of ultrasound was a piezoceramic transducer with a waveguide, mounted at the bottom of the chamber. The vibrating surface (i.e. ultrasound emitter) of the waveguide was 15 mm in diameter and its resonance frequency was 41.9 kHz. The Non-Contact Vibrometer UVM-3M was used to measure vibration amplitude of the emitter surface and to calibrate the amplitude sensor. All vibration amplitudes A cited in this paper are zero-to-peak. The test chamber was filled with the test liquid, which had previously been kept at chosen temperature for 5h and subjected to degassing by ultrasound for 20 min at a maximum transducer amplitude (22 microns). In so doing, the gas content (estimated mm^3/cm^3 by gas chromatography) decreased by 20- 25 % compared with the equilibrium value [4]. Preliminary partial degassing of the liquid considerably increased the reproducibility of the results, since after this treatment the gas content remained essentially unchanged under the influence of ultrasound during measurements. The rest time between two successive measurements was chosen to be 5 min on the basis of the results of [5]. The procedure of the measurements was as following. The capillary tube was immersed in the liquid and fixed in the prescribed position along the central axis of the chamber by means of a coordinate positioning mechanism. (Central axis of the chamber and of the waveguide of the transducer coincide with ±0.1 mm). The valve connecting the capillary–manometer–compressor system with the atmosphere was opened. Under the capillary forces, the liquid in the capillary tube rose to the height H_0. The valve was then closed and the ultrasound generator was turned on. Under the action of ultrasound within a suitable regime of sonification, the liquid tended to rise to a new height. The liquid was restored to its original position H_0 by using a compressor which increased the pressure over the meniscus in the capillary. The excess pressure ΔP_0 over the meniscus necessary to keep it at the level H_0 was measured by a manometer. Simultaneously the intensity of sonoluminescence (SL) was recorded. The

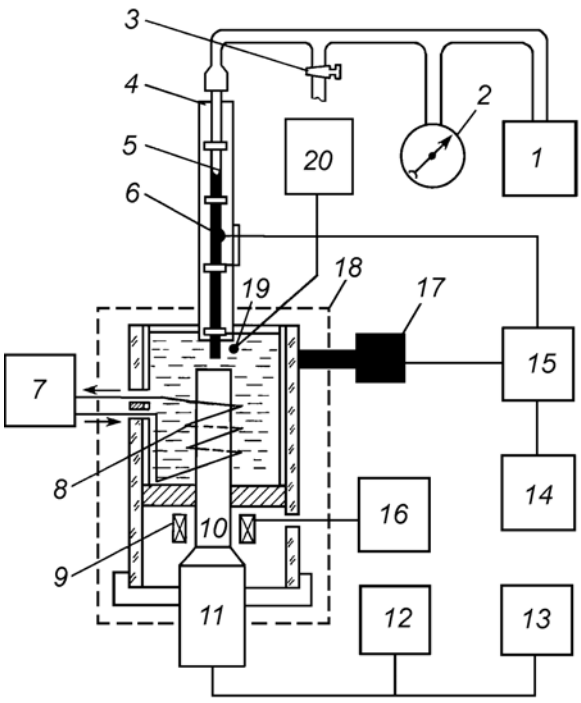

FIGURE 1. Schematic of the experimental arrangement: (1) compressor, (2) manometer, (3) valve, (4) guide plate of coordinate positioning mechanism, (5) capillary tube, (6) piezoelectric sensor, (7) thermo-stat, (8) coil, (9) amplitude sensor, (10) wave guide, (11) transducer, (12) frequency meter, (13) generator, (14) computer, (15) oscilloscope, (16) voltmeter, (17) photomultiplier, 18 - light-tight box, (19) thermocouple, (20) galvanometer.

measurements of ΔP_0 and SL in these experiments were accomplished after 2 minutes of sonification at the chosen amplitude.

The temperature of the liquid was monitored by the Chromel–Copel thermocouple which was placed at the distance of 5 mm at the capillary entrance. The temperature was maintained constant within ±1°C error limits in experiments with water and other low viscosity liquids and ±3°C in experiments with glycerin and water-glycerin mixture.

By computer control, a stepped ramp signal was produced which, by controlling the function generator, was used in experiments devoted to the measurements of the threshold amplitudes of the phenomena studied. The emitter vibration amplitude could be held constant for a certain period, and then increased to the next highest value by stepped ramp. In our experiments the ramping sequence consisted of increasing amplitude A to a set value for 5 s, then to a higher value for 5 s, etc., until SL or UCE manifested itself. The step size was 0.1 micron for amplitudes in the range 0-2 microns; and 0.5 microns for amplitudes in the range 2-15 microns.

RESULTS

Figs. 2 and 3 show the variation in both SL and UCE (as measured by the increase in pressure ΔP_0 required to keep the meniscus stationary when the ultrasound is turned on), both measured 2 minutes after the start of insonification, for two values of d (the distance between the butt-end of the capillary and the radiating surface). Note that because ΔP_0 is plotted on a linear scale and L is on a logarithmic one, the immediate visual impressions from the figures should be treated with caution, although the sub-threshold readings have been aligned (ΔP_0=0 Pa; L=10 mV). In Fig. 2 the threshold data points in L overlie exactly on those for ΔP_0 and for clarity are not shown. This would indicate exact correlation of the threshold for d=0.05 mm, though this is not maintained at d=5 mm (Fig. 3). The general form, that the activity in both ΔP_0 and L rises steeply from the threshold, and attains a maximum as the driving amplitude A increases, is held for all three liquids at d=5 mm (Fig. 3), but not for ΔP_0 in water and water-glycerin mixtures (curves 2 and 3) at d=0.05 mm (Fig. 2) (though,

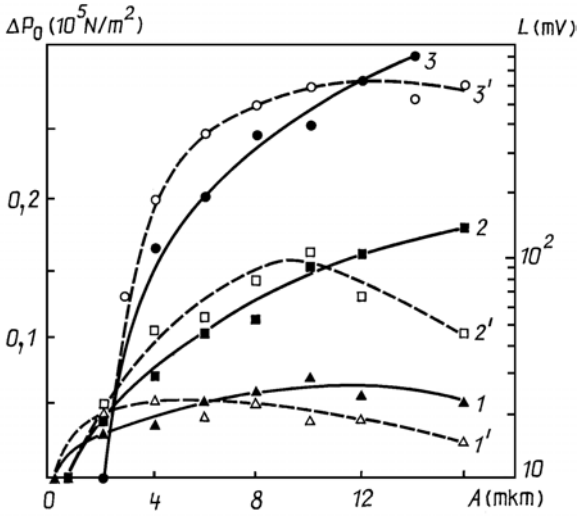

FIGURE 2. SL intensity L (dashed lines) and pressure ΔP_0 (solid lines) for different liquids: (1, 1′) acetone; (2, 2′) water; (3, 3′) 40% (by weight) water to 60% glycerin mixture. Each point is the average of 3 independent measurements (T = 23°C, d = 0.05 mm).

speculatively, this may simply be because the maximum value of A is insufficient to reveal this trend). For a given super-threshold setting of A, both ΔP_0 and L are greatest in the water/glycerin mix, least in acetone, with water giving intermediate values.

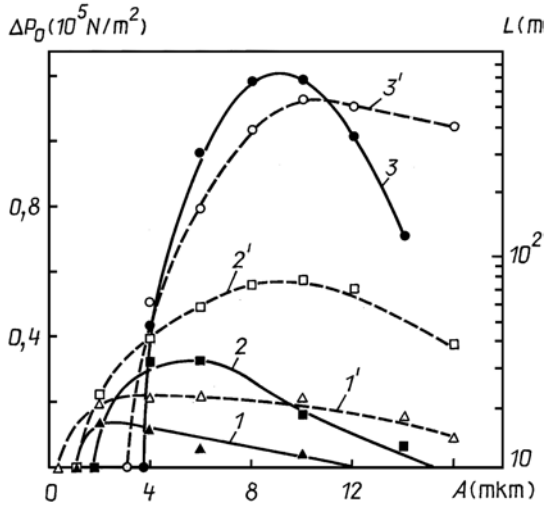

FIGURE 3. SL intensity L (dashed lines) and pressure ΔP_0 (solid lines) for different liquids: (1, 1′) acetone; (2, 2′) water; (3, 3′) 40% (by weight) water to 60% glycerin mixture. Each point is the average of 3 independent measurements (T = 23°C, d = 5 mm).

CONCLUSIONS

When UCE and SL are compared in a multibubble system driven at varying amplitudes A, the general form of both measurables (similarity in threshold; presence of a maximum as A increases; agreement in ordering of output from test liquids) suggests that UCE has the potential to be a physically robust and inexpensive monitor for ultrasonic cavitation. There are differences in the detail (such as the value of A at which the maximum occurs), which may relate to the fact that SL is usually generated from the spatial maxima of the pressure field whilst UCE monitors at the location of the capillary butt-end. These warrant further investigation.

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